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Radiation characteristics of four-element circular array of equilateral triangular patch microstrip antenna in plasma medium

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Abstract : An analysis of a new type of four-element circular array of equilateral triangular patch microstrip antenna is discussed at frequency 10 GHz. The array factor and far-zone EM-mode and P-mode radiation fields of the array geometry are derived using vector wave function techniques and pattern multiplication approaches. The results are obtained both in plasma medium and in free space and compared with those of single element triangular patch microstrip antenna. Some important antenna parameters such as radiation conductance, directivity and quality factor are computed for different ratios of plasma to source frequency. It is observed that radiation characteristics of this array geometry are modified considerably in the presence of plasma medium.

Keywords : Microstrip circular array, radiation properties, plasma medium.

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Within past three decades, microstrip antennas and their arrays have evolved as a major innovative activity within the antenna field and it has indeed been a fascinating and challenging experience to play a part in this vibrant field of research [1–4]. Microstrip antenna array can be classified either as a fixed beam or as an electronic scanning arrays. With the help of phased arrays, the main beam can be scanned easily in any direction. In other words, the radiation from an array can be measured directly by controlling the phase excitation difference between the elements. Such antennas when mounted on aerospace vehicles, encounter plasma medium during their travel in space. It has been pointed out that the radiation properties of microstrip antennas in plasma medium are modified to a great extent due to the generation of electoacoustic waves in addition to electromagnetic waves [5–8]. The circular array is an array configuration of very practical interest. Its applications span over radio direction finding, air and space navigation, underground propagation, radar, sonar and many other systems.

The configuration and coordinate system of array antenna is shown in Figure1. It consists of four identical

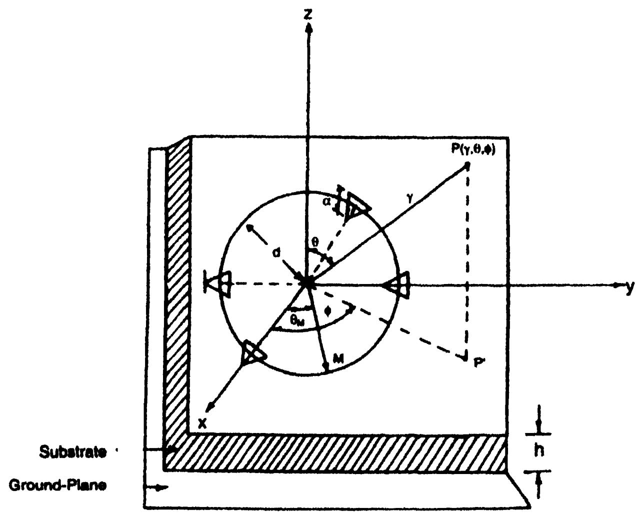

Figure 1. Configuration and coordinate system of four-element circular array of equilateral triangular patch microstrip antenna.

triangular microstrip patch element of arm length a, on a dielectric substrate of thickness h and substrate permittivity ε_r. The array element are placed in X–Y plane along a circular ring of radius d. The array elements are taken for the point M which moves such that it occupies

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uniform angular distance ($\phi_m = \pi/2$) between all four elements from X-axis. The progressive phase excitation difference between the patch is β_1. Each patch can be excited by a coaxial feed line from its corner. Among the various modes that may be excited in such disc resonators, we have considered TM_{nm} mode with respect to Z-axis. Here, n and m are the mode numbers associated with X and Y directions respectively.

Using linearized hydrodynamic theory of plasma, vector wave function technique and neglecting the coupling between the elements [9–12], the far-zone fields of the four-element circular array of triangular microstrip patch antenna are given as

EM-mode :

$$E_{\theta t} = -i\,\eta_0\omega_0[F_x\cos\theta\cos\phi + F_y\cos\theta\sin\phi] \times \sum_{m=1}^{4} \exp i\{\beta_e.d.\sin\theta\cos(\phi - \phi_m) + \beta_1\}.\, e^{-i\beta_e r}/r, \quad (1)$$

$$E_{\phi t} = -i\,\eta_0\omega_0[-F_x\sin\phi + F_y\cos\phi] \times \sum_{m=1}^{4} \exp i\{\beta_e.d.\sin\theta\cos(\phi - \phi_m)+\beta_1\}.\, e^{-i\beta_e r}/r, \quad (2)$$

and

P-mode :

$$E_{pt} = 2h\beta_p\omega_p^2/3a\omega_0\varepsilon_0(\omega_0^2-\omega_p^2) \times \exp(-i\beta_p r)/r \times \exp(-i\beta_p a.\sin\theta.\cos\phi/\sqrt{3}) \times \sum_{m=1}^{4} \exp i\{\beta_p.d.\sin\theta\cos(\phi - \phi_m) + \beta_1\} \times [E_{px} + E_{py}], \quad (3)$$

where $E_{\theta t}$, $E_{\phi t}$ = Component of total electric field vectors for EM-mode, E_{pt} = total electric field vector for P-mode, F_x = x-component of vector electric potential, F_y = y-component of vector electric potential, E_{px} = x-component of electric field vector for P-mode, E_{py} = y-component of electric field vector for P-mode. β_e = phase propagation constant for EM-mode given by $2\pi A/\lambda_0$, β_p = phase propagation constant for P-mode given by $\beta_e c/v$, c = velocity of light, v = root mean square thermal velocity of electron, A = plasma frequency parameter given by $(1-\omega_p^2/\omega_o^2)^{1/2}$, ω_p, ω_0 = angular plasma frequency and source frequency, η_0 = free space impedance equal to 120π ohms, β_1 = the progressive phase excitation difference between the patches.

The expression for total field pattern $R(\theta,\phi)$ is obtained as

$$R(\theta,\phi) = |E_{\theta t}|^2 + |E_{\phi t}|^2. \quad (4)$$

The values of $R(\theta,\phi)$ are calculated for a case taking f = 10 GHz, a = 1.3 cm, d =1.5 cm, n = 1, ε_r = 2.32 and the phase difference $\beta_1 = \pi/2$. The values of ϕ_m are chosen such that it has uniform and finite phase difference between two consecutive elements *i.e.* ϕ_1, ϕ_2, ϕ_3 and ϕ_4 have values $\pi/2$, π, $3\pi/2$ and 2π respectively from X-axis. The results are plotted in Figures 2 and 4 for two different planes (ϕ = 0 and $\phi = \pi/2$) for A = 1.0 *i.e.* in free space and in Figures 3 and 5 for two different planes (ϕ = 0 and $\phi = \pi/2$) for A = 0.5 *i.e.* in plasma medium.

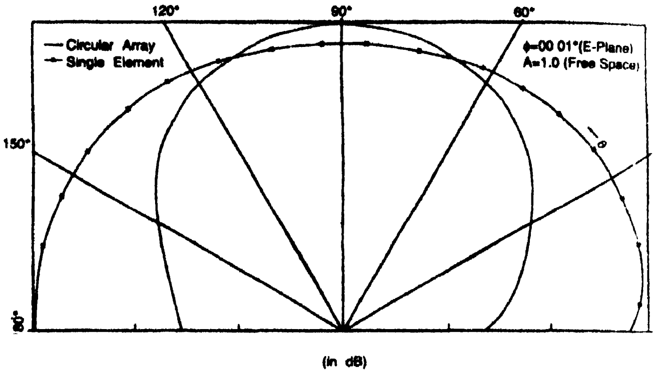

Figure 2. *E*-plane radiation patterns of four-element circular array and single element equilateral triangular patch microstrip antennas for A = 1.0 (free space).

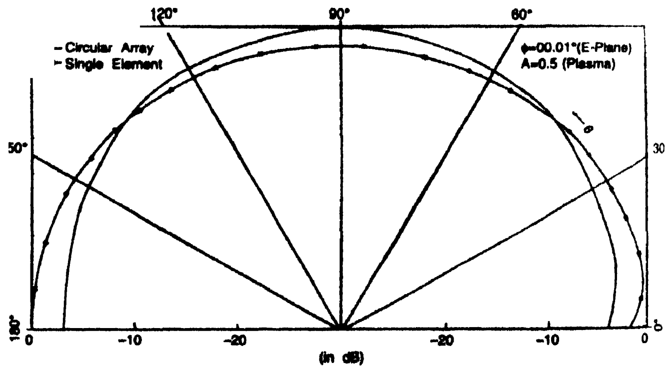

Figure 3. *E*-plane radiation patterns of four-element circular array and single element equilateral triangular patch microstrip antennas for A = 0.5 (plasma).

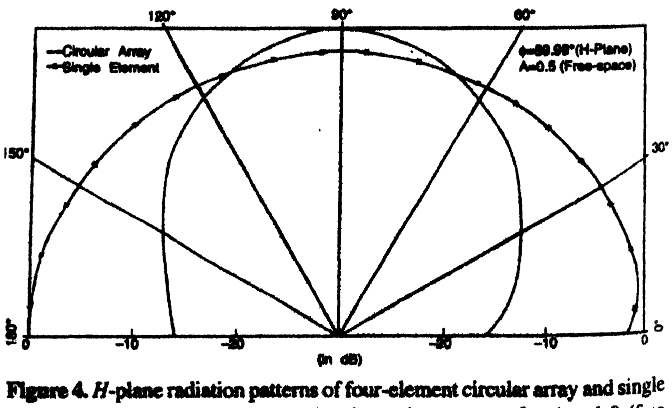

Figure 4. *H*-plane radiation patterns of four-element circular array and single element equilateral triangular patch microstrip antennas for A = 1.0 (free space).

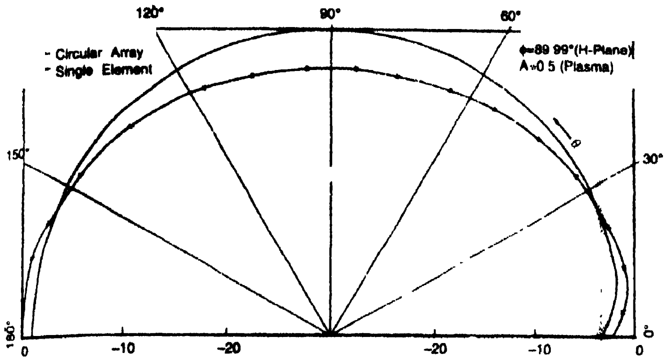

Figure 5. *H*-plane radiation patterns of four-element circular array and single element equilateral triangular patch microstrip antennas for $A = 0.5$ (plasma)

Radiation conductance :

The expression for radiated power in *EM*-mode is obtained using the relation [9,11].

$$P_e = (A/4\eta_0)\int_0^{2\pi}\int_0^{\pi} \{|E_{\theta t}|^2 + |E_{\phi t}|^2\}.r^2.\sin\theta.d\theta.d\phi. \quad (5)$$

The radiation conductance of an antenna in *EM*-mode can be defined as

$$G_e = 2.P_e/V_0^2. \quad (6)$$

The values of G_e are computed in Table 1.

Table 1. Calculated values of radiation conductance, directivity and quality factor for four-element circular array of equilateral triangular patch microstrip

S. No.	Plasma parameter (A)	Radiation conduction (G_e)	Directivity (D_e)	Quality factor (Q_e)
1	1.0	3.393	6.903	0.006
2.	0.8	1.105	5.603	0.018
3.	0.7	0.633	4.973	0.032
4.	0.6	0.375	3.501	0.054
5.	0.5	0.226	3.530	0.090
6.	0.4	0.138	3.324	0.147
7.	0.3	0.084	3.522	0.242
8.	0.2	0.048	4.401	0.424
9.	0.1	0.022	4.401	0.930

Directivity :

The directivity of an antenna is defined as the ratio of the maximum radiation intensity (power per unit solid angle) to the average radiation intensity. It can be expressed as

$$D_e = 4.\pi\{\text{Max.}(|E_{\theta t}|^2 + |E_{\phi t}|^2)\}/ \int_0^{2\pi}\int_0^{\pi}|E_{\theta t}|^2 + |E_{\phi t}|^2 r^2.\sin\theta.d\theta.d\phi. \quad (7)$$

The values of D_e are computed in Table 1.

Quality factor :

A parameter specifying frequency selectivity of a resonant circuit is the quality factor Q, which can be defined as the ratio between energy stored in the system and the energy lost.

The total Q of a microstrip radiating element comprises contributions due to the radiation Q_r, conductor loss Q_c, and dielectric loss Q_d, so

$$1/Q_t = 1/Q_r + 1/Q_c + 1/Q_d, \quad (8)$$

where $Q_r = \omega_0.W_t/P_r$,

$$Q_c = \omega_0.W_t/P_c = (\pi.f.\mu.\sigma)^{1/2}.h,$$

$$Q_d = \omega_0.W_t/P_d = 1/\tan\delta.$$

Here, W_t is the energy stored in the antenna element, P_c and P_d are power loss factors due to the conductors and dielectric, respectively, σ is the conductivity of the conductors.

The values of Q_e are computed in Table 1.

On the basis of the studies given in this paper, it is found that the presence of plasma medium modifies the radiation characteristics of the array geometry significantly. From Figures 2 to 5 which illustrate the *EM*-mode radiation field patterns of the antenna for free space (A = 1.0) and plasma (A = 0.5), it is clear that the shape of the field patterns has been modified to a great extent and also the field intensity redistributes considerably in plasma medium. The variation in several antenna parameters with plasma parameter (A) values in *EM* mode are shown from the Table 1. It is observed from the Table 1, the radiation conduction (G_e) is maximum in free space (A = 1.0) and decreases slightly on decreasing the plasma parameter (A) value. The low values of quality factor (Q_e) of antenna in free space indicates that antenna is radiating power more effectively in free space. Hence at low values of A, energy radiated in the form of plasma waves, which increases the quality factor of antenna in plasma medium. In free space, the *EM* mode directivity (D_e) of antenna is higher than that in plasma medium. To conclude, the theoretical results obtained in the present study, may be very useful specially for space vehicles because such type of array antennas can be mounted on the flat surface as well as on the curved surface vehicles.

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